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ABSTRACT

Computerized science simulations were employed by high school biology students in an attempt to enhance their problem-solving skills. The simulations were administered under unguided (discovery learning) and guided (guided discovery learning) conditions while a control group received no simulations. To ascertain the effectiveness of the simulations in enhancing problem-solving abilities, performance was compared on: (1) subsequent unit pretests; (2) standardized tests measuring scientific thought processes; and (3) a standardized test of critical thinking. Results indicate that the students using the simulations met the unit objectives at least as well as the control students. In addition, students using the guided version of the simulations surpassed the other students on the subsequent simulation pretests, on the tests of scientific thinking, and on the test of critical thinking. In most cases, students using the guided version of the simulations developed these generalized skills more effectively than those using an unguided version. These results suggest that the computerized simulations can help high school students substantially increase their problem-solving abilities. However, to be most effective, it appears that the simulations should be integrated with curriculum objectives and should provide guidance to direct students to use the simulations efficiently. (Author/JN)

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Computerized Science Simulations
Stimulus to Generalized Problem Solving Capabilities

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Paper presented at the annual convention of the American Educational Research Association, New Orleans, Louisiana, April 24, 1984.

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Computer Simulations to Stimulate Scientific Problem Solving

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(Abstract)

Computer simulations were employed by high school biology students in an attempt to enhance their problem solving skills. The simulations were administered under two conditions: (1) Unguided (discovery learning) and (2) Guided (guided discovery). In addition a control group received no simulations. To ascertain the effectiveness of the simulations in enhancing problem solving abilities, performance was compared on (1) subsequent unit pretests, (2) standardized tests measuring scientific thought processes, and (3) a standardized test of critical thinking.

The results indicate that (1) the students using the simulations met the unit objectives at least as well as the control students, and (2) the students using the guided version of the simulations surpassed the other students on the subsequent simulation pretests, on the tests of scientific thinking, and on the test of critical thinking.

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The problem solving literature suggests that we learn to solve specific problems by learning increasingly complex sets of rules and generalizing these rules to new situations. This process of acquiring specific problem solving skills is facilitated by reinforced practice (e.g., DeCecco, 1974).

Although many theorists find it convenient to speak of a general problem-solving skill, attempts to teach such a generalized skill have proven to be ineffective (DeCecco, 1974; Hudgins, 1977; Gagne, 1977).

In spite of this absence of empirical strategies for developing generalized problem-solving abilities, theoretical formulations for developing these abilities do exist (e.g., Bruner, 1973).

The empirical and theoretical research, therefore, suggests that generalized problem-solving skills could successfully be taught if sufficient reinforced practice could be arranged. According to this line of reasoning, previous attempts have failed because it is very difficult to provide reinforced practice for these generalized problem-solving skills.

One approach to teaching generalized problem-solving skill is to teach a large number of specific problem-solving strategies and to help students learn when to apply these strategies in novel situations (Maltzman, Eisman, and Brooks, 1956). If this is done then learners will be able to solve a large variety of problems and perhaps develop the more generic coding system proposed by Bruner (1973). However, because of the great amount of time needed to set up novel problems for students to solve, many classroom teachers are unable or unwilling to present the wide variety of problems that this approach would require.

The computer can provide students in classrooms an opportunity to learn problem-solving skills. By interacting with computerized simulation programs, students can in a single class session solve more problems than they would otherwise solve in a much greater time period. In addition, they can solve problems which would otherwise be expensive or dangerous, and they can repeat variations of these problems at no cost or risk until they thoroughly understand

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the concepts, principles, and heuristics involved in the solution of the problem. A further advantage of the computerized simulation compared to textbook problems is that the student's involvement is much more active and the feedback is much more rapid. In short, the computer gives many of the advantages of the textbook without its monotony and remoteness.

Few attempts have been made to study the effect of the use of computer simulations in science on either scientific or general problem-solving ability. Hughes (1974) found no significant differences in science problem-solving ability between students in laboratory, combined computer laboratory and computer simulation groups. Alternatively, Donaldson (1972) found students in computer supplemented science classes seem to be using the problem-solving strategies generated in those classes in non-computer science classes. This inference was based on informal observation of some students in the experimental group.

The present study employed computer simulations to enhance general problem-solving skills. Computer simulations presented a variety of problem situations for participants to solve. While the participants solved these problems correctly, they were expected to acquire a wide variety of specific problem-solving skills. In addition, because the simulations required essential research and idea-generating strategies, the participants were expected to integrate these specific strategies into an enhanced overall problem-solving strategy.

In addition, the effects of guidance while the the problem solvers were interacting with the simulations was examined to ascertain whether a discovery-oriented use of computer simulations is more effective than a guided use of the simulations. The success of the computer simulations in developing problem solving abilities was ascertained by analysis of posttest scores on problem-solving tasks varying in degree of remoteness from the type of problems in the simulations.

Method

The participants were predominantly ninth grade students in two school systems in a midwestern metropolitan area. (A few students were from higher grade levels, taking the biological science course.) The study was conducted in three settings. School 1 was in a large high school in a highly populated metropolitan area. Its students were mostly black and of middle-class and lower-middle-class socioeconomic status. All the students in six beginning biological science courses during the 1981-82 school year participated in the study. The students in six other beginnirg biological science classes in the same school served as controls.

During the 1982-83 school year, the teachers from six schools in a highly industrial city participated in the study. (School 1 was one of the schools in this city.) In each school, half the students of the participating teachers used the simulations and the other half served as controls. This set of six schools is jointly referred to as School 2 in this report.

During the 1982-83 school year, the students in an additional suburban high school also took part in the study. These students were predominantly white and of middle-class or upper-middle-class socioeconomic status. The school had twelve ninth-grade biological science classes. The students from each of the twelve biological science classes in this school served in one of the experimental groups or in the control group. This school is referred to as School 3 in this report.

Independent Variable

The main independent variable was the administration of the computer simulations. TRS-80 or Apple II Plus microcomputers were installed in the schools, and the teachers were briefly instructed in the use of the computers and programs. Part of this instruction consisted of learning guidelines for integrating the computer simulations with their regular classroom and laboratory instruction. (These guidelines are routinely available with the computer programs.) The students in the experimental classes then interacted with the computers as an integrated part of their science courses. A list of the programs employed in the study is included in Appendix A. Because of constraints imposed by the availability of the programs and by the structure of the curricula, different programs were sometimes used in different phases of the program.

In addition, there were two levels of guidance (Guided and Unguided). The guidance was supplied as part of the computer program, and therefore structuring the guidance and providing it to designated students was easily accomplished.

In each school, the content of the courses was held as constant as possible. Each teacher had at least two courses in the study, and the experimental and control courses were matched as closely as possible with regard to the content covered during the study.

Field Testing of Programs

During a preliminary phase of the project, an attempt was made to develop a stockpile of approximately 20-30 computer simulations which teach specific scientific problem-solving strategies. The main criteria for inclusion in this pool of simulations were (1) that the program

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simulate an experiment that is normally treated within the biological science curriculum of the school using the program, (2) that the program have clearly stated objectives, and (3) that there be clearly stated methodologies for ascertaining whether these objectives were attained.

It quickly became obvious that there was not a pool of 20-30 computer simulations from which to draw programs. However, the Computer Biology Laboratories, published by Diversified Educational Enterprises, met these criteria. Therefore seven of these Laboratories (Appendix A) were selected for use in this project.

After potential computer simulations were selected, the simulations were field tested in schools that resembled the schools that would take part in the main phase of the study. This field testing provided a basis for formative evaluation and modification of the simulations. Guidelines such as those developed by McGuire et al. (1976) for developing simulations and by Dick and Carey (1978) for the formative evaluation of curriculum materials were followed throughout this developmental phase of the project.

Dependent Variables

The dependent variables were of four types:

(1) The performance of the students was monitored on the pretest for each simulation. Improved performance on successive pretests would indicate a generalized ability to solve problems.

(2) The BSCS Process of Science Test was administered as a measure of problem solving ability in science.

(3) The Test of Integrated Process Skills (TIPS) was administered to measure the maturity of the processes the students employed to solve problems in science.

(4) The Watson-Glaser Critical Thinking Appraisal was administered to measure ability to make inferences, to recognize assumptions, to deduce conclusions, to decide whether or not conclusions are warranted, and to evaluate the strength of arguments.

Pretest, posttest, and gain scores for appropriate groups were compared using the BREAKDOWN, ANOVA and ONEWAY programs from the Statistical Package for the Social Sciences (Nie et al., 1975). In addition to the gain score analysis, the posttests of appropriate groups were compared using analysis of covariance, with the pretest scores as the covariate. For all analyses, exact levels of significance were reported. This is more appropriate than reporting alpha levels of .05 or .01 (Freedman, Pisani, and Purves, 1978).

Results

This report actually presents the results of three separate studies which overlap and replicate one another. Each separate study employed a non-random control-group pretest-posttest quasi-experimental design. In the absence of a true experimental design, an overlapping series of quasi-experimental designs often provides a good strategy to control the major threats to internal validity (Cook and Campbell, 1979; Vockell, 1983).

For the sake of clarity, the hypotheses and results for School 1, School 2, and School 3 will be reported separately. Afterwards, a brief discussion (see Table 51) will summarize and integrate these results.

SCHOOL 1

In School 1, the TIPS and Form ZM of the Watson-Glaser test were administered to the students during regular class sessions in October, 1981. Between November and April, the students in these classes used five computer simulations to help them meet course objectives covered during that time period. The simulations were PLANT, OSMO, MONOCROSS, BALANCE, and MOTHS.

Before studying each unit, the students took the unit mastery test as a pretest; and after completing each unit, the students took the same unit mastery test as a posttest. Four of the classes used the Guided version of each simulation. Another set of four classes used the Unguided version of the same simulations. The remaining four classes pursued the same objectives (included as part of the documentation accompanying the simulations and matched to normal curriculum requirements) through normal teaching methods (lecture, discussion, teacher questioning, and other media), without using the computer simulation at all.

An unforseen circumstance was that two of the teachers in School 1 became seriously ill during the course of the study and temporarily had to stop teaching. For reasons unrelated to the study, the teachers who replaced these two teachers did not participate in the study. This meant that half the classes unexpectedly dropped out of the study after using only three simulations (PLANT, OSMO, and MONOCROSS), while the other half used all five of the simulations.

In May, 1982, the students were scheduled to take the TIPS and Form A of the Watson-Glaser test as posttests. The two classes whose teachers had been replaced were unavailable for these posttests. In addition, one of the remaining two teachers did not administer the TIPS posttest.

In summary, the students in School 1 consisted of three

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groups (Guided, Unguided, and Control). Pretest-posttest comparisons were available on all students for only the first three simulations. For half the students (2 Guided classes, 2 Unguided classes, and 2 Control classes), there were pretest-posttest data for all five tests and for the Watson-Glaser test. Finally, for one-fourth of the students (2 Control classes and an Unguided class), there was also pretest-posttest data on the TIPS.

The following hypotheses were stated for School 1:

1. The students in the Guided and the Unguided groups would master the unit objectives at least as well as the Control students. No significant differences were expected among the posttest performances of these groups.

2. The students would show a gradual increase in performance on the unit pretests. The gain in performance of the Guided students would be greatest, the Control students least, and the Unguided students in between.

3. The Guided students would show significantly greater gains on the posttest Watson-Glaser test than the Control students. The Unguided students would fall in between the other two groups.

4. The Unguided students would gain significantly more gain on the TIPS posttest than the Control group.

Results for School 1

Tables 1 to 5 and Figures 1 to 5 summarize the results of the pretest and posttests on the unit mastery tests and compare the gains made by the various groups for each of these units. In three cases, there was no significant difference in the gain scores. In the other two cases (PLANT and BALANCE) the Guided students gained more than the others, and the Unguided students gained more than the Control students. Overall, the results in Table 1 to 5 provide support for Hypothesis 1.

Insert Tables 1 to 5 and
Figures 1 to 5 about here.

Table 6 presents the data to test the second hypothesis. The results of an analysis of variance before the massive dropouts (Table 7) and at the end of the series of five simulations (Table 8) indicate that the computer users gained more on the pretests than did the Control students. The gains of the Guided and Unguided students did not differ significantly from each other. The results in Tables 6 to 8 provide strong support for Hypothesis 2.

Insert Table 6 to 8 about here

Table 9 and Figure 6 summarize the results of the Watson-Glaser test at School 1. These results indicate that the Guided students gained significantly more than either of the other two groups. It is important to note that the apparent "losses" of two of the groups are actually a result of transfer to Form A from Form ZM of the Watson-Glaser, and not an indication of an actual reduction in critical thinking ability. In actual fact, as Table 25 shows, the Guided students progressed from the 14th to the 72nd percentile, while the Control students went from the 19th to the 60th percentile.

Insert Tables 9 & 10 and
Figure 6 about here

Tables 11 to 15 summarize the results of the individual Watson-Glaser subtests at School 1. On subtests 2 and 3 (Tables 12 and 13), there were no differences among the groups. In each of the other three cases, there was a tendency for the Guided students to surpass the other two groups. In each of these cases, the Unguided students performed slightly worse than the Control students.

Insert Tables 11 to 15 about here

These results partially support Hypothesis 3. The Guided students followed the hypothesized pattern, but the Unguided students did not.

Table 16 and Figure 6 present the results of the TIPS. These results indicate that the Unguided students performed slightly (nonsignificantly) more poorly than the Control students on the posttest. It is important to note that only a few students took the TIPS posttest. These results lend no support to hypothesis 4.

Insert Table 16 & Figure 6 about here

SCHOOL 2

In School 2 (actually a combination of six separate schools), the BSCS test, the TIPS, and the Watson-Glaser tests were administered to all the students in the experimental and control groups in late September and early October, 1982. The experimental students then used the guided versions of seven computer simulations to cover objectives normally covered in their biology curriculum. The simulations included PLANT, OSMO, MONOCROSS, DICROSS, BALANCE, MOTHS, and POLLUTE. Since these students took only the unit posttests (with no pretests), unit scores were not recorded for School 2. In May, at the end of the school year and a month after the final simulation, the students retook

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as posttests the BSCS test, the TIPS, and an alternate form of the Watson-Glaser test.

In order to minimize interference with the regular curriculum resulting from excessive testing, only the major pretests and posttests were scheduled, with no unit pretesting. (Teachers used the unit tests as a regular part of their grading procedures.) In addition, because of limited facilities and because of the previous year's experience indicating that the Unguided condition was not particularly successful at School 1, only a Guided condition and a Control condition were included at School 2.

The following hypotheses were stated for School 2:

1. The experimental (Guided) students would gain significantly more on the BSCS posttest than the control students.

2. The experimental (Guided) students would gain significantly more on the TIPS posttest than the control students.

3. The experimental (Guided) students would gain significantly more on the Watson-Glaser posttest than the control students.

4. On the Watson-Glaser subtests, the experimental (Guided) students would gain more than the control students on subtests 1, 4, and 5, but the gains would be approximately equal on subtests 2 and 3.

Results for School 2

Table 17 and Figure 7 present the results of the BSCS tests at School 2. These results indicate that both groups made modest gains between the pretest and the posttest. The difference in gain scores between the two groups was not significant. These results lend no support to hypothesis 1.

Insert Table 17 & Figure 7 about here

Table 18 and Figure 8 present the TIPS results for School 2. These results indicate that the experimental (Guided) students gained significantly more than the Control students. These results support Hypothesis 2.

Insert Table 18 & Figure 8 about here

Table 19 and Figure 9 present the overall Watson-Glaser results. These results indicate that while the Control group moved from the 5th to the 27th percentile between the pretest and the posttest, the experimental (Guided) students progressed from the 8th to the 63rd percentile. These results support Hypothesis 3.

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Insert Table 19 & Figure 9 about here.

Table 20 to 24 present the results for the individual Watson-Glaser subtests. On Subtest 1, as hypothesized, the experimental (Guided) students gained significantly more than the control students. On subtests 2 and 3, as hypothesized, there was no significant difference between the two groups. On Subtest 4, as hypothesized, the experimental (Guided) students gained significantly more than the control students. However, on Subtest 5, contrary to hypothesis, there was no significant difference between the two groups. In four out of five cases, therefore, the results supported Hypothesis 4.

Insert Tables 20 to 24 about here

SCHOOL 3

In School 3, the BSCS test, the TIPS, and Form YM of the Watson-Glaser test were administered the students in all three groups (Guided, Unguided, and Control) during January, 1983. The students then used four of the simulations (MONOCROSS, MOTHS, BALANCE, and POLLUTE). Before studying each unit, all students took the unit mastery test as a pretest; and after completing the unit, the students took the same test as a posttest. Finally, at the end of the semester, the BSCS test, the TIPS, and Form YM of the Watson-Glaser test were readministered as a posttest.

The following hypotheses were stated for School 3:

1. The students in the Guided and the Unguided groups would master the unit objectives at least as well as the Control students. No significant differences were expected among the posttest performances of these groups.

2. The students would show a gradual increase in performance on the unit pretests. The gain in performance of the Guided students would be greatest, the Control students least, and the Unguided students in between.

3. The Unguided students would show significantly greater gains on the BSCS posttest than the Control group.

4. The Unguided students would show significantly greater gains on the TIPS posttest than the Control group.

5. The Guided students would show significantly greater gains on the Watson-Glaser posttest than the Control students. The Unguided students would fall in

between the other two groups.

Results for School 3

Tables 25 to 28 summarize the results of the pretest and posttests on the unit mastery tests and compare the gains made by the students in the various groups for each of these units. In only one case (POLLUTE, Table 34) did the differences even approach significance; and in this case this resulted largely from the fact that the pretest score for the Guided group had already become substantially higher than that of the control group (16.29 vs. 15.09), and therefore further improvement was less likely. These results provide support for Hypothesis 1.

Insert Tables 25 to 28 about here

Table 29 shows the percentages of correct responses on each of the consecutive pretests. These results indicate that, as hypothesized, the students using the computer simulations gained significantly more between the first and last pretest than did the control students. Contrary to hypothesis, however, the Unguided students (partially because of their lower initial score) gained more than the Guided students. Table 30 summarizes the gains for each group on each of the subsequent pretests. Table 30 includes only those students who took the first (MONOCROSS) pretest and the other designated pretest, whereas Table 26 includes all the students. The Table 30 results conform to the pattern designated in Hypothesis 2.

Insert Tables 29 and 30 about here

Table 31 and Figure 10 summarize the results of the BSCS tests at School 3. These results indicate that the Guided students gained the most, the Control students gained the least, and the Unguided students gained an intermediate amount. These results strongly support Hypothesis 3.

Insert Table 31 & Figure 10 about here

Table 32 and Figure 11 present the results of the TIPS at School 3. These results indicate that there were no significant differences among the groups in their rate of gain on the TIPS. These results provide no support for Hypothesis 4.

Insert Table 32 and Figure 11 about here

Table 33 and Figure 12 present the results for the Watson-Glaser test at School 3. These results indicate that there were no significant differences among the three groups in their rate of gain. These results provide no support for Hypothesis 5.

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Insert Table 33 & Figure 12 about here

Discussion and Conclusions

Table 34 summarizes the results from the five schools. In general, of the 13 hypotheses, 8 were supported. The only clear contradiction occurred for Hypotheses 3 at School 1. At that school, on the Watson-Glaser test, the Guided students surpassed the others (as hypothesized), but the Unguided students actually gained less than the Control students.

Insert Table 52 about here

The results strongly indicate that students using the simulations mastered the instructional objectives for each unit "at least as well" as students taught through conventional methods.

In addition, it is useful to consider the informal perceptions of the teachers. In both the two schools in which the programs were field tested and in the schools in which the actual studies took place, the teachers intended to continue using the programs after the university's support was withdrawn. The reasons the teachers most frequently gave were (1) the students seemed to learn from them, (2) the programs were cost effective, (3) the computerized experiments were easier to set up and run than conventional experiments, (4) the support materials made it easy to integrate the simulations into the curriculum and to evaluate student performance, and (5) while the students used the computers, the teachers themselves would be able to individualize in other ways.

The teachers made these judgments before they had access to the formal data contained in this report. It seems proper to say that simulations of this type would be useful instructional tools, even if they did nothing more than help students meet the objectives of isolated instructional units. However, the results of this report indicate that such simulations can promote additional generalized outcomes as well.

One evidence of generalized benefits was the significant difference in cumulative pretest gains. In both schools where individual unit scores were available (Schools 3 and 1) there was a pattern of increased pretest performance by the Guided students compared to the Control students. The Unguided students fell in between.

Additional evidence for a generalized impact from the use of the simulations can be found in an examination of the TIPS and BSCS results. On the Test of Integrated Process Skills (TIPS), there was no significant difference in

performance among the three groups in School 3. In School 2, there was a significant difference in favor of the experimental (Guided) students over the Control students. In School 1, (with a very small number of students, none of whom received the Guided treatment) there was a nonsignificant trend in favor of the Unguided falling in between. These results indicate that students who use simulations develop generalized problem solving skills in areas associated with science at least as well as those taught through conventional methods, and perhaps better.

Evidence for an even more broadly generalized impact can be found in an examination of the Watson-Glaser scores. On that test, there was no difference among the three groups at School 3. In evaluating this non-significance at School 3, it is important to note that only four months passed between the pretest and posttest. In the other two schools, there were seven months between pretest and posttest, allowing more time for this highly generalized skill to develop. At School 2, the Guided students performed significantly better than the Control students. In School 1, the Guided students performed significantly better than the Guided or Control students, while these latter two groups did not differ in performance.

On the specific Watson-Glaser subtests, the groups did not differ on the "Deduction" or "Recognition of Assumptions" portions. The most consistent differences appeared on the "Inference" subtest. On this test, the School 2 Guided students significantly surpassed the Control students, and the School 1 Guided students significantly surpassed the Control students, with the Unguided students doing even worse than the Controls. On the "Interpretation" subtest, the Guided students in School 2 significantly surpassed their Control counterparts, while the Guided students in School 1 exceeded the Unguided and the Control students. On the "Evaluation of Arguments" subtest, there were no differences in School 2, but in School 1 the Guided students surpassed the Control students, with the Unguided students performing the worst.

In summary, there were no cases of significantly superior performance by the control group. In several cases, the performance of the Guided students was superior to that of the control students, and in most of these cases the performance of the Guided students was also superior to that of the Unguided students. The superiority of the Guided students was least pronounced on the specific unit tests and appeared more strongly on the more generalized measures of problem solving ability. The superior performance of the Guided subjects on subsequent pretests showed an ability to generalize from one unit to another. In addition, the Guided students showed superior performance in four out of seven cases on the standardized tests of generalized problem solving ability.

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These results suggest that the use of computer simulations that require students to solve problems causes students to develop generalized problem solving skills. The variation in the results among the various schools may be attributed to differences in strategies employed by the control teachers or to initial difference in the students. For example, some teachers may promote a degree of interactive problem solving analogous to that provided by the computer; and weaker students (School 1 and 2) were able to gain more than initially stronger students (School 3) on the standardized test of critical thinking.

The major differences between the students using the simulations and those using more traditional approaches were (1) the students using the simulations were often able to become more interactively involved with specific scientific experiments, and (2) the students using the simulations were often able to replicate the experiments and benefit from the results of earlier trials. As the students ran successive simulations, they were able to apply to subsequent simulations strategies they had actively employed (perhaps several times) during previous simulations. This cumulative development of problem solving ability was reflected in the improved performance on unit pretest scores.

In addition, the students appear to have seen similarities between what they did during these numerous trials at the computer and the problem solving situations that appeared on the standardized tests. The result was that students were able to generalize their problem solving skills far beyond the original computerized settings.

The Guided presentations of the computer simulations were consistently superior to the Unguided versions. The guidance was extremely simple, often taking less than 30 seconds to read. This brief guidance appears to have focused the attention of the students on the objectives and proposed strategies to meet those objectives of the units in such a way as to help them spend their time at the simulations more efficiently. Not all educational computer simulations provide such guidance. It would be useful to determine whether similar segments of guidance could enhance the effectiveness of other computerized simulations in science and in other areas.

On the Watson-Glaser test, the simulations were most effective at enhancing the students' abilities on the Inference and Interpretation subtests. The Inference subtest measures the ability to discriminate among degrees of truth or falsity of inferences drawn from given data. This was the activity most frequently performed during the simulations, even though the examples on the test were usually drawn from outside the field of biological science. The students using the simulations probably either performed this activity more

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often or were more actively involved in the process than the Control students and were therefore more easily able to apply this skill in new situations.

The Interpretation subtest measures the ability to weigh evidence and to decide whether generalizations or conclusions based on the given data are warranted. Again, this activity closely resembles that performed in the simulations, even though the items on the test were usually outside the field of biological science. The students using the simulations probably either performed this activity more often or were more actively involved in the process than the Control students and were therefore more easily able to apply this skill in new situations.

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In one school, the students using the simulations were also superior on the Evaluation of Arguments subtest, but in the other school they were not. This subtest measures the ability to distinguish between arguments which are strong and relevant and those which are weak or irrelevant to a particular question or issue. The simulations did not provide direct practice at this activity, and improvements in this ability would have occurred because of an overlap between this skill and the skills measured by the Inference and Interpretation subtests.

In neither school were the simulation students superior to the control students on the Recognition of Assumptions or the Deduction subtests. The Recognition of Assumptions subtest measures the ability to recognize unstated assumptions or presuppositions which are taken for granted in given statements or assertions. The simulations contained no direct practice on these activities. However, it is noteworthy that the manuals accompanying the simulations state the assumptions behind each of the simulations themselves. A useful activity would be either (1) to build into the simulations or ancillary materials strategies to help the students focus on the nature and importance of these assumptions or (2) to encourage the teachers to help students identify the important assumptions that underly each simulation. Either of these strategies would perhaps lead to improvements in the skill measured by this subtest. An accurate conclusion, therefore, would be that although the simulations had the potential to enhance the ability of students to recognize assumptions, the simulations were not implemented in such a way as to tap this potential.

The Deduction subtest measures the ability to determine whether specified conclusions necessarily follow from information in given statements or premises. This ability should be developed by performing activities like those in the simulations. However, the students using the simulations did not display a significant advantage over the controls on this subtest. It may be useful, therefore, to restructure the simulations (or ancillary materials) to focus more

specifically on the formal logic necessary for effective deductive reasoning.

There were other variables that could not be examined in the present study. For example, The presentation of problems in lifelike settings is more likely than traditional methods to stimulate insight, intuition, and other factors associated with productivity. The use of simulations like those described in this study are likely to have an impact on these elements of creativity. Future research should explore such possibilities.

Summary

Students using computerized science simulations in beginning biological science classes met the unit objectives at least as well as the control students. In addition, the students using the simulations often surpassed the control students on the pretests for subsequent units, on tests of measuring scientific thought processes, and on a test of critical thinking. In most cases, the students using the Guided version of the simulations developed these generalized skills more effectively than those using an Unguided version.

These results suggest that computerized simulations can help high school students substantially increase their problem solving abilities. To be most effective, it appears that these simulations should be integrated with curriculum objectives and should provide guidance to direct students to use the simulations efficiently.

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Tables and Figures

Note: Some tables contain two separate F-Ratios. When this occurs, the first is the result of an analysis of variance of the gain scores. The second is an analysis of covariance of the posttest scores, with the pretest scores as the covariate. In most cases, the results are nearly identical.

TABLE 1

PLANT unit pretest, posttest, and gain scores at School 1.

[Standard Deviations in parentheses.]

	PRE	POST	GAIN	
Control (n=112)	7.95 [3.30]	11.88 [4.16]	4.05	[4.81]
Unguided (n=61)	7.52 [3.53]	12.28 [4.44]	4.98	[4.71]
Guided (n=53)	7.02 [3.46]	13.40 [4.14]	6.38	[4.28]
F-Ratio			4.51	3.27
d.f.			2.223	2.222
Sig.			.02	.04

TABLE 2

OSMO unit pretest, posttest, and gain scores at School 1.

[Standard Deviations in parentheses]

	PRE	POST	GAIN	
Control (n=117)	6.46 [2.68]	6.97 [3.06]	0.51 [3.32]	
Unguided (n=56)	6.57 [2.95]	7.38 [2.63]	0.81 [3.14]	
Guided (n=47)	6.64 [3.03]	7.43 [3.17]	0.79 [3.56]	
F-Ratio			0.40	0.49
d.f.			2,216	2,215
Sig.			.68	.62

TABLE 3

MONOCROSS unit pretest, posttest, and gain scores at School 1.

[Standard Deviations in parentheses].

	PRE	POST	GAIN	
Control (n=110)	6.07 [2.95]	7.46 [3.09]	1.39 [3.03]	
Unguided	7.67 [2.57]	9.09 [3.10]	1.42 [2.92]	
Guided	6.81 [3.03]	8.56 [3.41]	1.74 [2.73]	
F-Ratio			0.28	1.64
d.f.			2,218	2,217
Sig.			.76	.20

TABLE 4

BALANCE unit pretest, posttest, and gain scores at School 1.

[Standard Deviations in parentheses].

	PRE	POST	GAIN	
Control (n=54)	16.02 [3.85]	16.52 [4.10]	0.50	[3.81]
Unguided (n=31)	15.74 [3.56]	17.23 [4.31]	1.48	[3.32]
Guided (n=20)	17.70 [4.40]	20.65 [2.39]	2.95	[3.49]
F-Ratio			3.45	6.84
d.f.			2,102	2,101
Sig.			.04	.002

TABLE 5

MOTHS unit pretest, posttest, and gain scores at School 1.

[Standard Deviation in parentheses]

	PRE	POST	GAIN	
Control (n=51)	13.98 [3.52]	14.55 [4.80]	0.57	[4.27]
Unguided (n=17)	15.41 [4.26]	17.53 [3.73]	2.12	[2.64]
Guided (n=35)	15.31 [3.91]	16.26 [5.03]	1.24	[3.74]
F-Ratio			1.08	1.62
d.f.			2,100	2,99
Sig.			.35	.21

TABLE 6

Percentages of correct performance on each of the unit pretests at School 1.

	PLANT	OSMO	MONO	BAL	MOTH
Control	31.8	38.0	43.4	61.6	53.8
Unguided	30.1	38.7	54.8	60.6	59.3
Guided	28.1	39.1	49.7	68.1	58.9

TABLE 7

Gains on the first three pretest [prior to massive dropouts].

	PLANT	MONO	GAIN	ANOVA			ANACOVA		
				F-Ratio	d.f.	Sig.	F-Ratio	d.f.	Sig.
Control			11.1 (m=94)						
Unguided			26.7 (m=53)						
Guided			23.0 (m=49)	11.47	2, 191	.001	9.87	2, 190	.001

TABLE 8

Gains on unit pretests during the entire series of simulations.

	PLANT	MOTH	GAIN	ANOVA			ANACOVA		
				F-Ratio	d.f.	Sig.	F-Ratio	d.f.	Sig.
Control			25.6 (n=42)						
Unguided			32.9 (n=16)						
Guided			28.7 (n=35)	1.37	2, 90	.26	1.61	2, 89	.21

TABLE 9

Overall Watson-Glaser pretest, posttest, and gain scores at School 1.

[Standard Deviations in parentheses]

	PRE	POST	GAIN	
Control	47.26 [7.78]	43.33 [6.60]	-3.82	[7.42]
Unguided	45.40 [6.53]	40.33 [7.10]	-4.93	[8.82]
Guided	45.00 [10.61]	46.18 [7.64]	1.18	[9.52]
F-Ratio			3.13	4.74
d.f.			2,90	2,89
Sig.			.05	.02

TABLE 10

Overall Watson-Glaser pretest, posttest, and gain scores at School 1.

[Expressed in percentiles].

	PRETEST	POSSTEST	GAIN
Control	26%-ile	60%-ile	34%-ile
Unguided	21%-ile	45%-ile	24%-ile
Guided	20%-ile	72%-ile	52%-ile

TABLE //

Performance on Subtest 1 [Inferences] of the Watson-Glaser test at School 1.

	PRE	POST	GAIN	
Control (n=52)	4.87 [2.52]	5.48 [2.07]	0.62	[2.79]
Unguided (n=31)	5.35 [1.94]	5.61 [2.32]	0.26	[2.35]
Guided (n=22)	5.50 [2.42]	7.18 [2.59]	1.68	[2.42]
F-Ratio			2.05	4.31
d.f.			2.102	2.101
Sig.			.14	.02

4

TABLE 12

Performance on Subset 2 [Recognition of Assumptions] of the Watson-Glaser test at School 1.

	PRE		POST		GAIN	
Control (n=52)	8.88	[2.99]	9.40	[2.99]	0.71	[3.74]
Unguided (n=31)	8.19	[2.52]	8.68	[2.46]	0.48	[3.55]
Guided (n=22)	8.22	[2.51]	9.09	[2.86]	0.86	[2.55]
F-Ratio					0.08	0.45
d.f.					2,101	2,102
Sig.					.93	.65

TABLE 13

Performance on Subtest 3 [Deduction] of the Watson-Glaser test at School 1.

	PRE	POST	GAIN	
Control (n=52)	12.40 [3.29]	8.67 [2.24]	-3.73	[3.87]
Unguided (n=31)	12.10 [2.95]	8.19 [2.17]	-3.90	[2.99]
Guided (n=22)	12.77 [3.96]	9.32 [2.32]	-3.19	[4.80]
F-Ratio			0.23	1.51
d.f.			2,102	2,101
Sig.			.80	.23

TABLE 14

Performance on Subtest 4 (Interpretation) of the Watson-Glaser test at School 1..

	PRE	POST	GAIN	
Control (n=49)	11.82 [2.74]	9.33 [2.10]	-2.35	[3.17]
Unguided (n=31)	11.32 [2.82]	8.81 [2.30]	-2.52	[3.42]
Guided (n=20)	11.10 [3.86]	10.30 [2.98]	-0.80	[4.40]
F-Ratio			1.71	2.58
d.f.			2,96	2,98
Sig.			.19	.09

TABLE 15

Performance on Subtest 5 (Evaluation of Arguments) of the Watson 5–Glaser test at School 1.

	PRE	POST	GAIN	
Control (n=46)	9.09 [1.80]	10.22 [2.46]	1.13 [2.79]	
Unguided (n=30)	8.43 [2.19]	8.87 [2.84]	0.43 [3.60]	
Guided (n=17)	8.24 [3.27]	11.12 [2.69]	2.88 [2.89]	
F-Ratio			3.46	4.52
d.f.			2,90	2,89
Sig.			.04	.02

TABLE 16

TIPS pretest, posttest, and gain scores at School 1.

(Standard Deviations in parentheses.)

	PRE	POST	GAIN	
Control (n=32)	16.19 [4.48]	13.84 [5.14]	-2.13	[4.00]
Unguided (n=14)	15.79 [4.41]	15.21 [3.87]	-0.57	[3.96]
Guided	———	———	———	
F-Ratio			1.47	1.78
d.f.			1.43	1,43
Sig.			.24	.19

52

TABLE 17

BSCS pretest, posttest, and gain scores at School 2.

(Standard Deviations in parentheses.)

	PRE	POST	GAIN	
Control (n=64)	13.94 [5.15]	14.63 [5.62]	0.69 [5.56]	
Unguided (n=92)	16.75 [5.68]	17.38 [7.24]	0.63 [8.16]	
Guided	———	———	———	
F-Ratio			0.00	0.00
d.f.			1,154	1,154
Sig.			.97	.10

TABLE 18

TIPS pretest, posttest, and gain scores at School 2.

(Standard Deviations in parentheses.)

	PRE	POST	GAIN	
Control (n=69)	15.75 [4.00]	14.94 [6.94]	-0.81	[6.62]
Unguided (n=91)	16.68 [4.44]	18.23 [6.71]	1.55	[5.18]
Guided	———	———	———	
F-Ratio			6.42	7.23
d.f.			1,158	1,157
Sig.			.02	.008

TABLE 17

Overall Watson-Glaser pretest, posttest, and gain scores at School 2.

(Standard Deviations in parentheses.)

	PRE	POST	GAIN
Control	30.55 [5.49] (5%-ile)	36.55 [10.48] (22%-ile)	6.00 [11.65]
Unguided	31.94 [3.83] (8%-ile)	44.59 [3.59] (63%-ile)	12.65 [5.77]
Guided	———	———	———
F-Ratio			4.57 8.62
d.f.			1,35 1,34
Sig.			.04 .006

TABLE 20

Performance on Subtest 1 (Inferences) of the Watson–Glaser test at School 2:

	PRE	POST	GAIN	
Control (n=45)	2.76 [1.54]	4.69 [2.26]	1.93 [2.49]	
Unguided (n=20	2.10 [1.45]	7.50 [1.85]	5.40 [2.64]	
Guided	———	———	———	
F-Ratio			25.85	23.85
d.f.			1.63	1,62
Sig.			.0001	.001

TABLE 21

Performance on Subtest 2 (Recognition of Assumptions) of the Watson–Glaser test at School 2.

	PRE	POST	GAIN	
Control (n=44)	7.52 [1.87]	8.73 [3.08]	1.20	[3.45]
Unguided (n=20)	7.95 [1.64]	9.40 [3.35]	1.45	[3.78]
Guided	———	———	———	
F-Ratio			0.07	0.54
d.f.			1,62	1,61
Sig.			.80	.47

TABLE 22

Performance on Subtest 3 (Deduction) of the Watson–Glaser test at School 2.

	PRE	POST	GAIN	
Control (n=41)	5.98 [1.75]	7.34 [2.85]	1.37	[2.79]
Unguided (n=20)	5.80 [1.54]	7.90 [2.34]	2.10	[2.69]
Guided	———	———	———	
F-Ratio			0.95	0.79
d.f.			1,59	1,58
Sig.			.34	.37

TABLE 23

Performance on Subtest 4 (Interpretation) of the Watson-Glaser test at School 2.

	PRE	POST	GAIN	
Control (n=33)	7.15 [2.32]	7.15 [2.53]	0.00 [3.48]	
Unguided (n=18)	7.50 [1.79]	9.00 [1.50]	1.50 [2.64]	
Guided	———	———	———	
F-Ratio			2.54	8.14
d.f.			1,49	1,48
Sig.			.12	.006

TABLE 21

Performance on Subtest 5 (Evaluation of Arguments) of the Watson–Glaser test at School 2.

	PRE	POST	GAIN	
Control (N=20)	7.05 [2.37]	8.60 [2.96]	1.55 [4.48]	
Unguided (N=17)	8.59 [2.15]	10.53 [1.66]	1.94 [2.36]	
Guided	———	———	———	
F-Ratio			0.11	0.00
d.f.			1,35	1,34
Sig.			.75	.99

TABLE 25

MONOCROSS unit pretest, posttest, and gain scores at School 3.

(Standard Deviations in parentheses.)

	PRE	POST	GAIN	
Control (n=111)	8.44 [2.86]	9.43 [2.63]	0.99	[2.77]
Unguided (n=97)	7.28 [3.06]	9.01 [2.57]	1.74	[2.84]
Guided (n=69)	8.45 [2.89]	9.51 [2.89]	1.05	[2.56]
F-Ratio			1.83	0.10
d.f.			2,274	2,273
Sig.			.17	.91

TABLE 26

MOTHS unit pretest, posttest, and gain scores at School 3.

[Standard Deviation in parentheses.]

	PRE	POST	GAIN	
Control (n=117)	14.93 [3.05]	16.75 [2.08]	1.82	[2.84]
Unguided (n=99)	14.36 [3.14]	16.89 [2.34]	2.53	[2.97]
Guided (n=70)	14.26 [3.39]	16.85 [2.48]	2.59	[2.84]
F-Ratio			2.31	0.95
d.f.			2,283	2,282
Sig.			.11	.39

TABLE 27

BALANCE unit pretest, posttest, and gain scores at School 3.

(Standard Deviation in parentheses.)

	PRE	POST	GAIN	
Control	13.46 [3.77]	16.65 [2.54]	3.19	[3.61]
Unguided	13.80 [2.66]	16.42 [2.29]	2.62	[2.96]
Guided	13.52 [3.59]	16.54 [2.83]	3.02	[3.59]
F-Ratio			0.53	0.36
d.f.			2,257	2,256
Sig.			.60	.70

TABLE 28

POLLUTE unit pretest, posttest, and gain scores at School 3 .

(Standard Deviations in parentheses.)

	PRE	POST	GAIN	
Control	15.09 [4.82]	19.40 [2.60]	4.31	[4.86]
Unguided	15.57 [3.61]	18.83 [3.07]	3.25	[4.12]
Guided	16.29 [4.43]	19.25 [2.21]	2.96	[4.17]
F-Ratio			2.51	1.40
d.f.			2,258	2,257
Sig.			.09	.25

TABLE 21

Percentages of correct performance each unit pretests at School 3.

	MONO	MOTH	BAL	POL
Control	60.3 (n=111)	71.1 (n=117)	64.1 (n=104)	62.9 (n=105)
Guided	52.0 (n=69)	68.4 (n=70)	65.7 (n=80)	64.9 (n=63)
Unguided	60.4 (n=97)	67.9 (n=99)	64.4 (n=94)	67.9 (n=93)

TABLE 30

Gains beyond the original baseline on each unit at School 3.

[expressed in percentages]

	MONO	MOTH	BAL	POL
Control	———	11.2 (n=111)	4.2 (n=103)	3.5 (n=101)
Unguided	———	6.9 (n=97)	5.1 (n=94)	9.2 (n=92)
Guided	———	14.9 (n=71)	10.7 (n=58)	12.2 (n=61)
F-Ratio		2.79 (2.10)	1.71 (0.50)	3.00 (2.07)
d.f.		2,276	2,252	2,251
Sig.		.07 (.12)	.18 (.61)	.06 (.13)

TABLE 31

BSCS pretest, posttest, and gain scores at School 3.

(Standard Deviations in parentheses.)

	PRE	POST	GAIN	
Control (n=99)	17.70 [5.42]	16.77 [6.78]	-0.93 [6.48]	
Unguided (n=68)	18.12 [4.88]	19.24 [6.52]	1.12 [5.03]	
Guided (n=99)	17.76 [5.27]	19.47 [6.86]	1.72 [6.03]	
F-Ratio			5.23	5.88
d.f.			2,263	2,262
Sig.			.006	.003

TABLE 32

TIPS pretest, posttest, gain scores at School 3.

(Standard Deviations in parentheses.)

	PRE	POST	GAIN	
Control (n=104)	18.09 [5.54]	20.59 [5.63]	2.52	[5.57]
Unguided (n=69)	18.62 [5.30]	20.10 [5.91]	1.48	[4.70]
Guided (n=90)	18.90 [5.22]	20.99 [5.81]	2.09	[5.12]
F-Ratio			0.83	0.69
d.f.			2,260	2,259
Sig.			.44	.50

TABLE 23

Watson–Glaser pretest, posttest, and gain scores at School 3.

(Standard Deviations in parentheses.)

	PRE	POST	GAIN	
Control (n=100)	51.20 [10.53]	51.97 [12.94]	0.77	[12.68]
Unguided (n=63)	53.03 [10.42]	52.17 [9.08]	-.86	[8.63]
Guided (n=94)	54.62 [9.10]	53.70 [8.33]	-.91	[8.63]
F-Ratio			0.78	0.15
d.f.			2,254	2,253
Sig.			.46	.87

TABLE 84-A

	SUPPORTING DATA	NEUTRAL DATA	CONTRADICTORY DATA	RELEVANT TABLES AND FIGURES
School 1 Hypotheses:				
1. The students in the Guided and the Unguided groups would master the unit objectives at least as well as the Control students. No significant differences were expected among the posttest performances of these groups.	X			Tables 1-5 Figures 1-5
2. The students would show a gradual increase in performance on the unit pretests. The gain in performance of the Guided students would be greatest, the Control students least, and the Unguided students in between.	X			Tables 6-8
3. The Guided students would show significantly greater gains on the posttest Watson-Glaser test than the Control students. The Unguided students would fall in between the other two groups.	X		X	Tables 9-15 Figure 6
4. The Unguided students would show significantly more gain on the TIPS posttest than the Control group.		X		Table 16 Figure 6

TABLE 34-B

Summary of Hypotheses

School 2 Hypotheses:	SUPPORTING DATA	NEUTRAL DATA	CONTRADICTORY DATA	RELEVANT TABLES AND FIGURES
1. The experimental (Guided) students would gain significantly more on the BSCS posttest than the control students.		X		Table 17 Figure 7
2. The experimental (Guided) students would gain significantly more on the TIPS posttest than the control students.	X			Table 18 Figure 8
3. The experimental (Guided) students would gain significantly more on the Watson-Glaser posttest than the control students.	X			Table 19 Figure 9
4. On the Watson-Glaser subtests, the experimental (Guided) students would gain more than the control students on subtests 1, 4, and 5, but the gains would be approximately equal on subtests 2 and 3.	X			Tables 20-24

TABLE 34-C

Summary of Hypotheses

School 3 Hypotheses:	SUPPORTING DATA	NEUTRAL DATA	CONTRADICTORY DATA	RELEVANT TABLES AND FIGURES
1. The students in the Guided and the Unguided groups would master the unit objectives at least as well as the Control students. No significant differences were expected among the posttest performances of these groups.	X			Tables 25-28
2. The students would show a gradual increase in performance on the unit pretests. The gain in performance of the Guided students would be greatest, the Control students least, and the Unguided students in between.	X			Tables 26-27
3. The Unguided students would gain significantly more gain on the BSCS posttest than the Control group.	X			Table 28 Figure 10
4. The Unguided students would gain significantly more gain on the TIPS posttest than the Contol group.		X		Table 29 Figure 11
5. The Guided students would show significantly greater gains on the Watson-Glaser posttest than the Control students. The Unguided students would fall in between the other two groups.		X		Table 30 Figure 12

FIGURE 1

PLANT unit pretest and posttest scores at School 1.

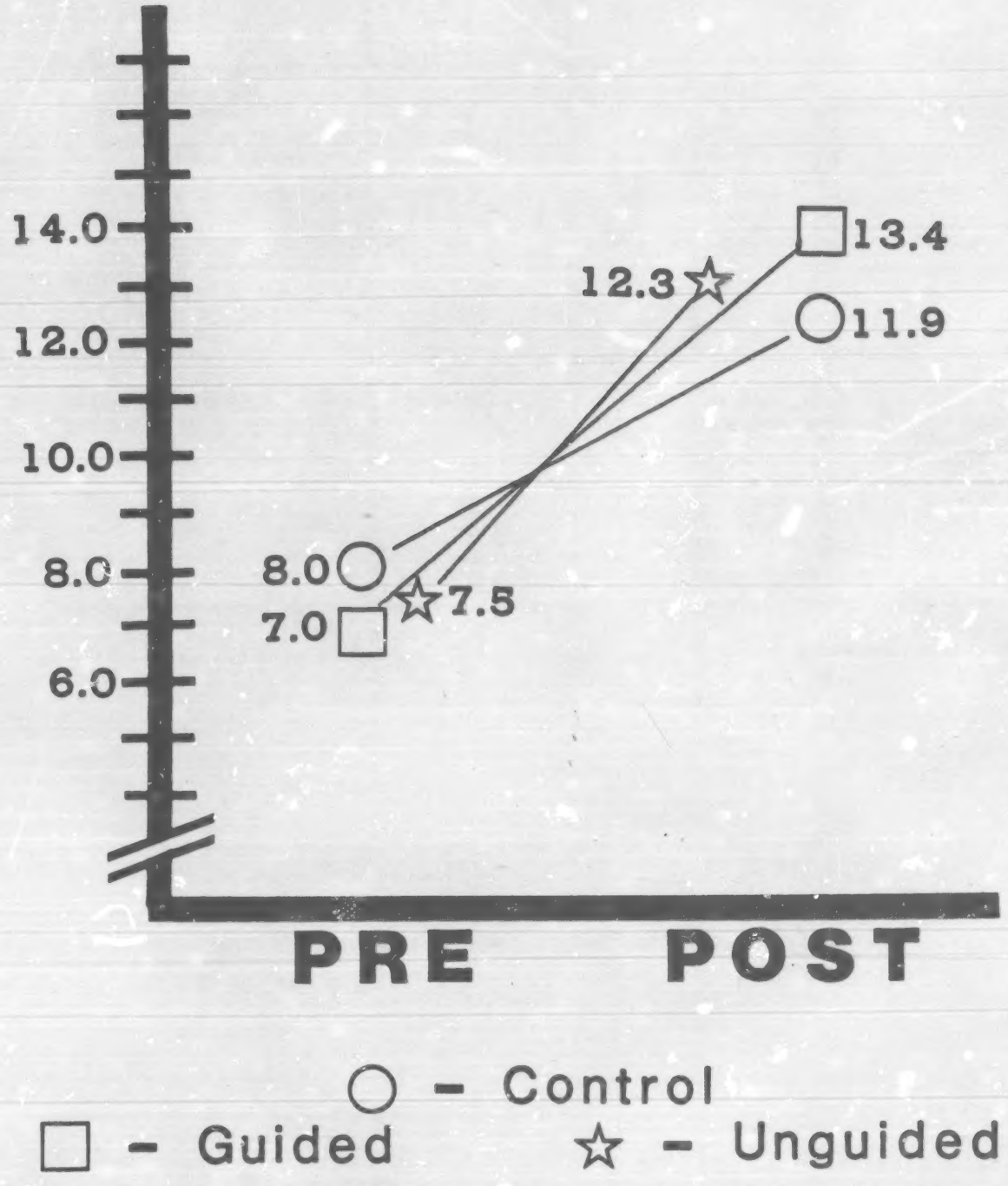


FIGURE 2

OSMO unit pretest and posttest scores at School 1.

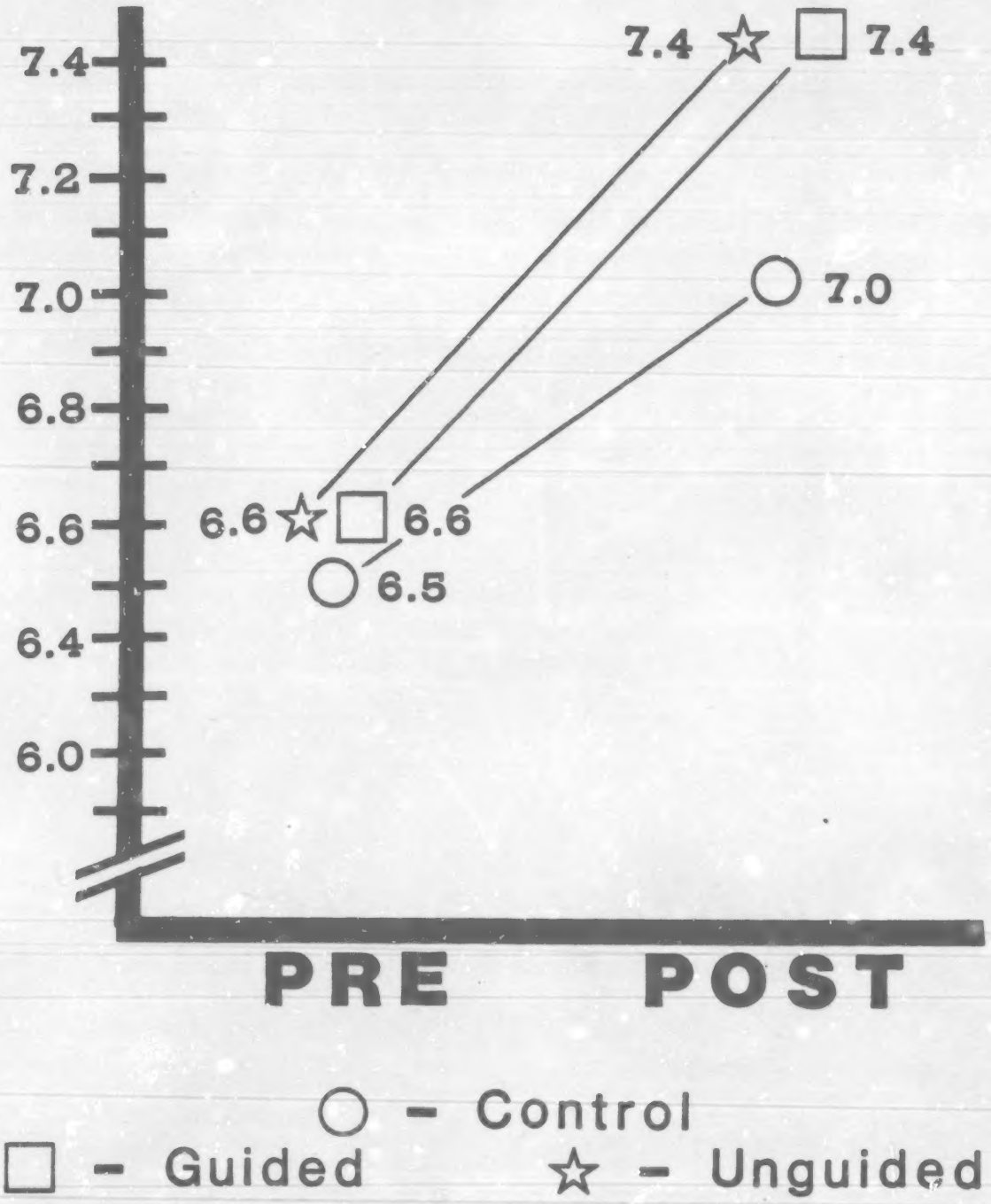


FIGURE 3

MONOCROSS unit pretest and posttest scores at School 1.

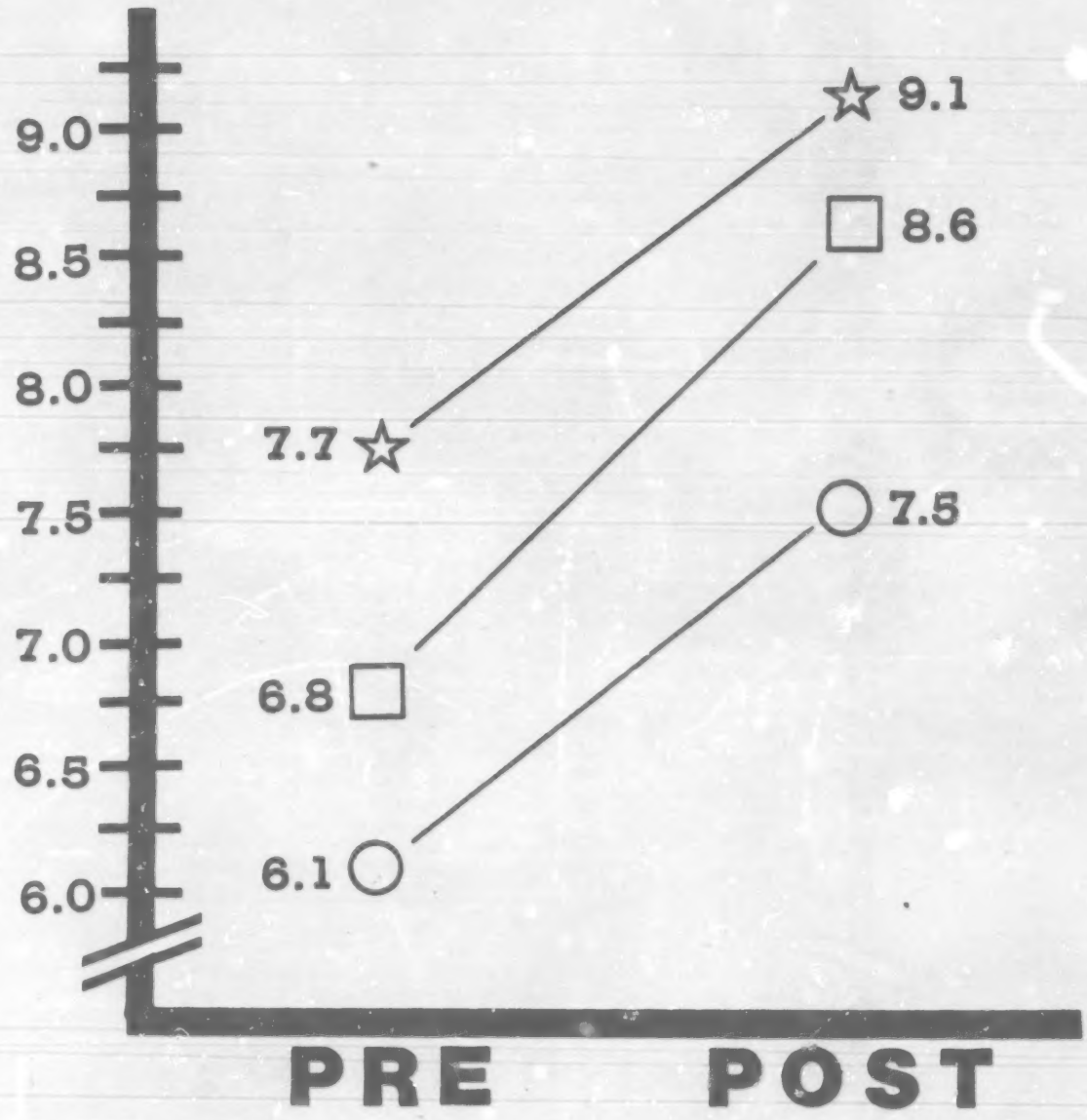


FIGURE 4

BALANCE unit pretest and posttest scores at School 1.

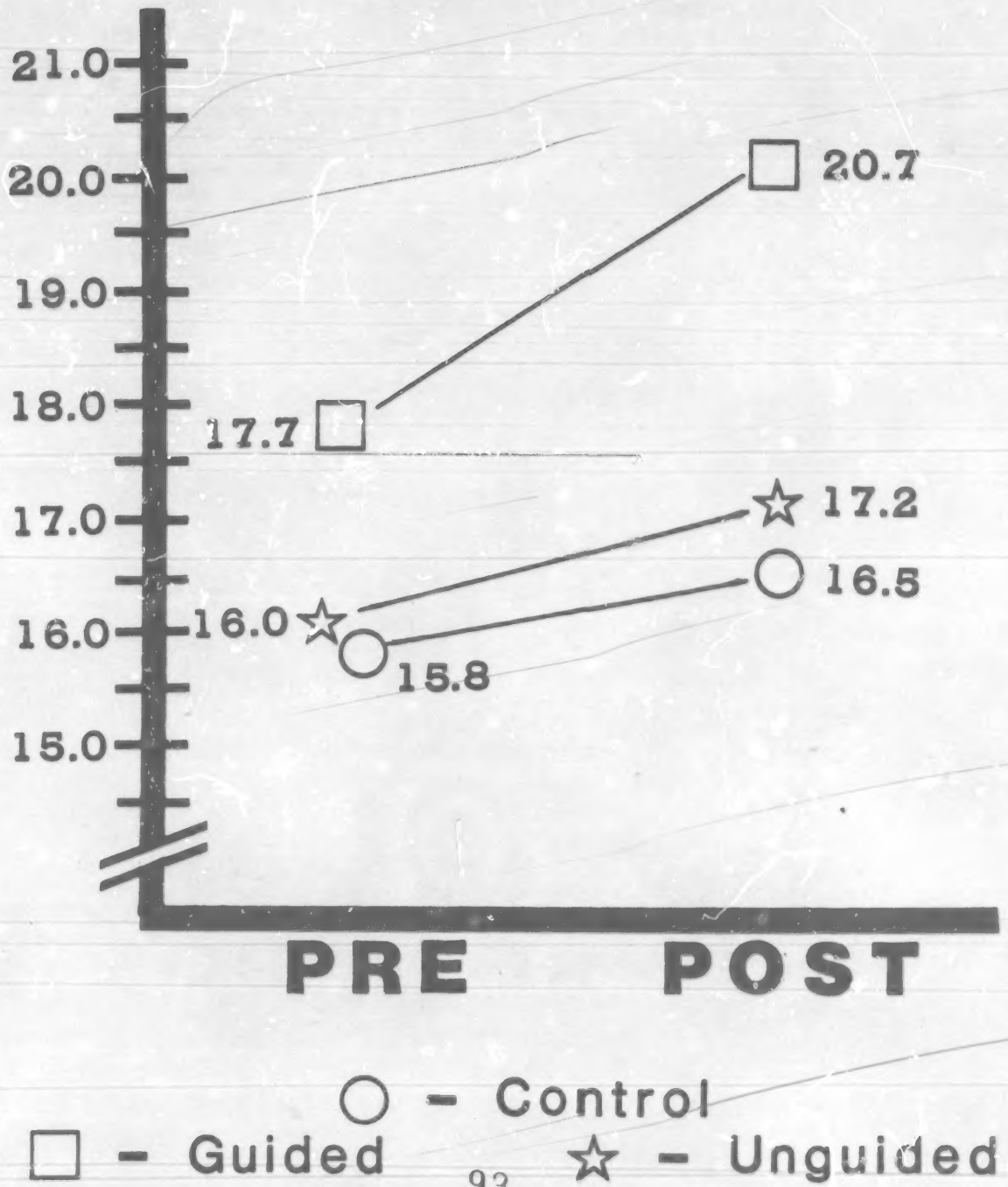


FIGURE 5

MOTHS unit pretest and posttest scores at School 1.

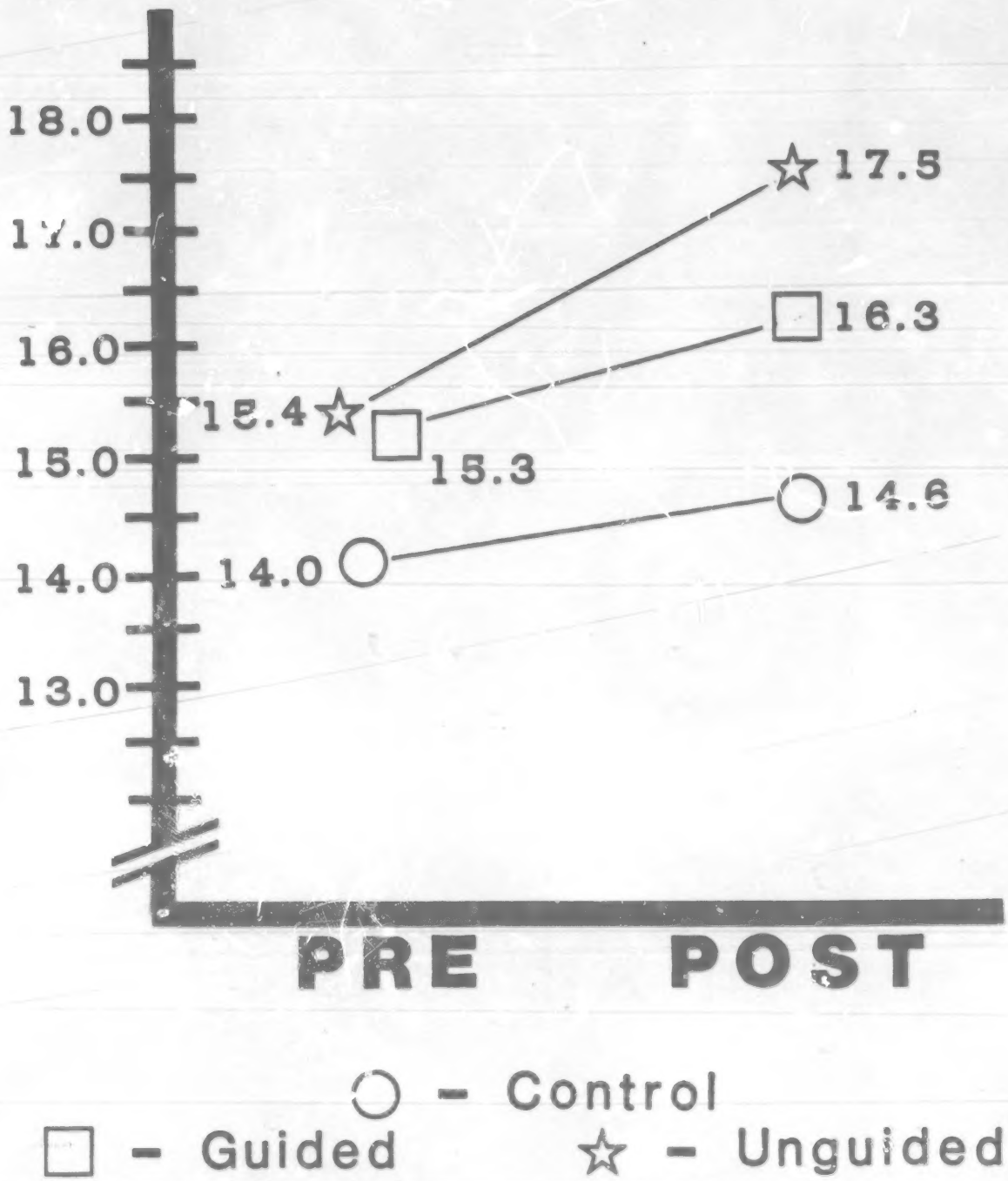


FIGURE 6

Overall Watson-Glaser pretest and posttest scores at School 1.

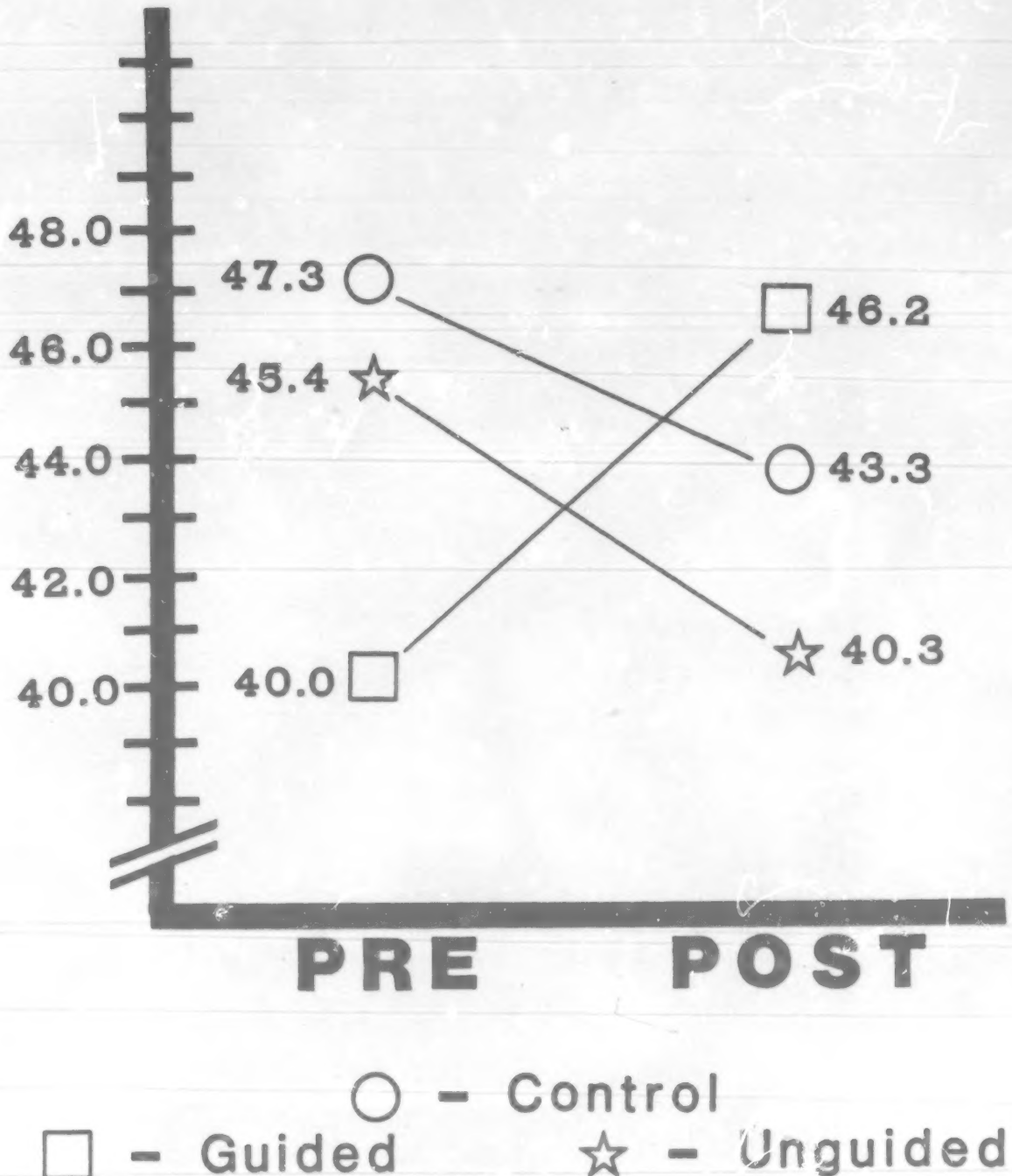


FIGURE 7

BSCS pretest and posttest scores at School 2.

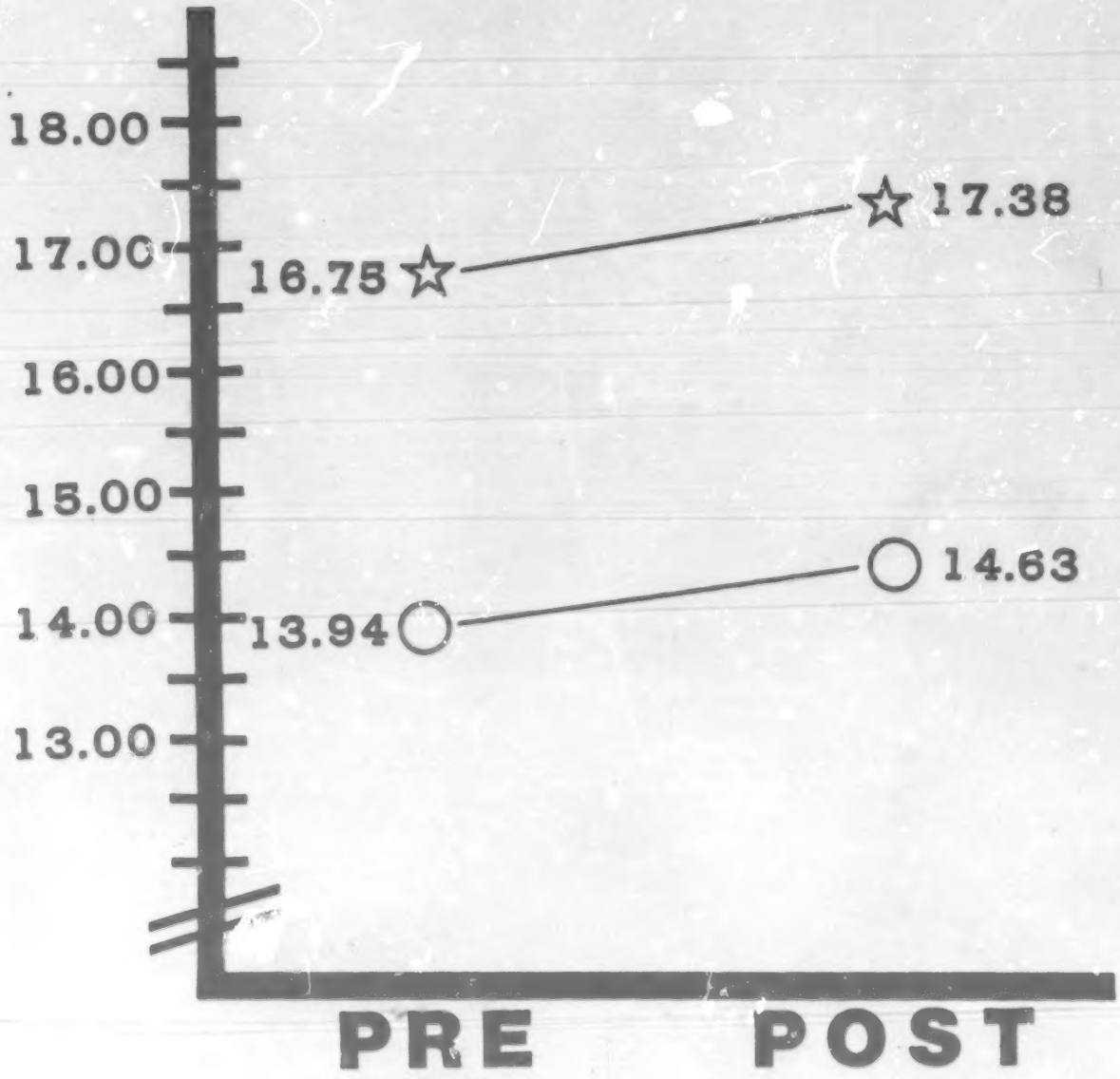


FIGURE 8

TIPS pretest and posttest scores at School 2.

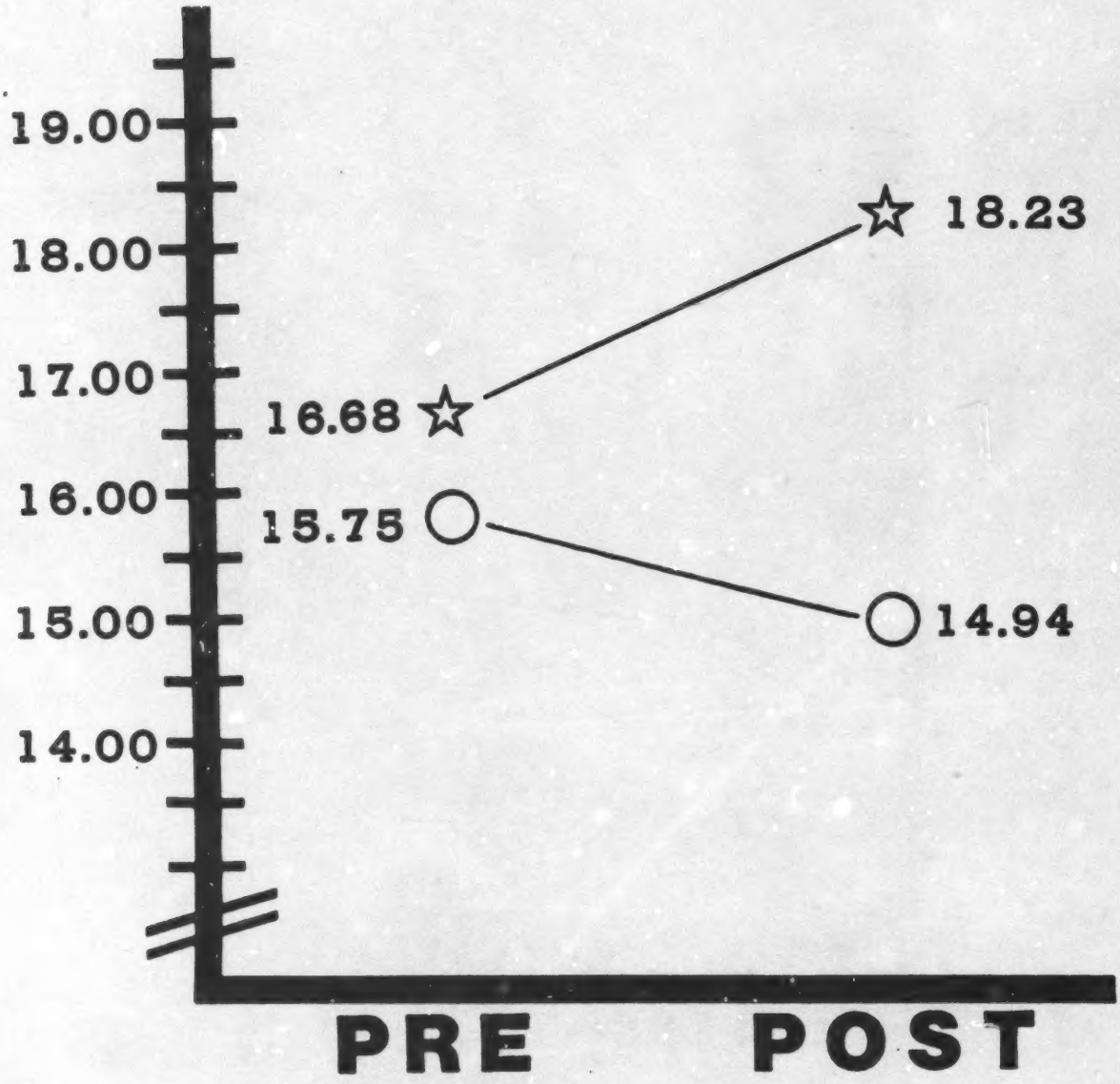


FIGURE 9

Overall Watson-Glaser pretest and posttest scores at School 2.

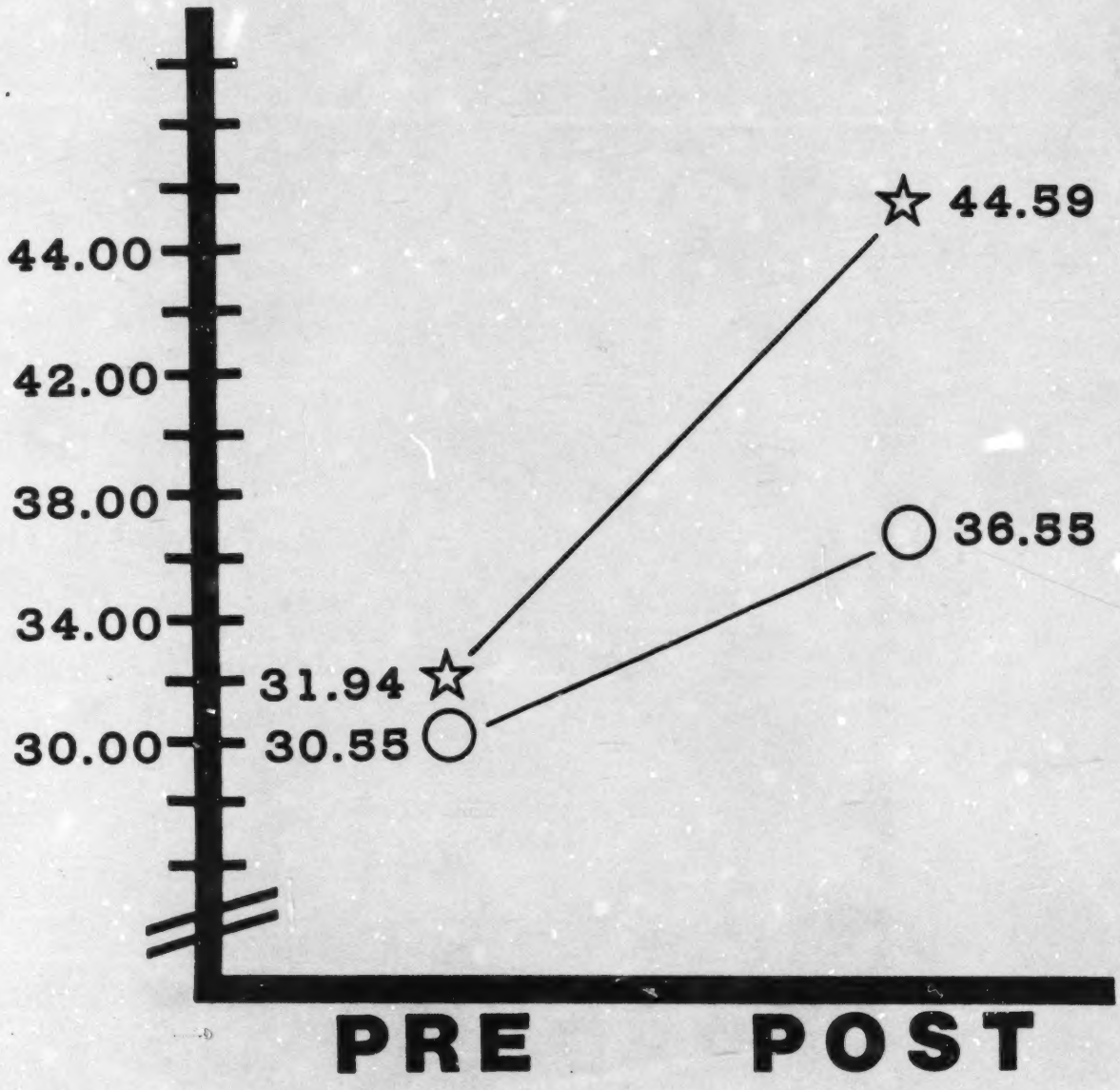


FIGURE 9

Overall Watson-Glaser pretest and posttest scores at School 2.

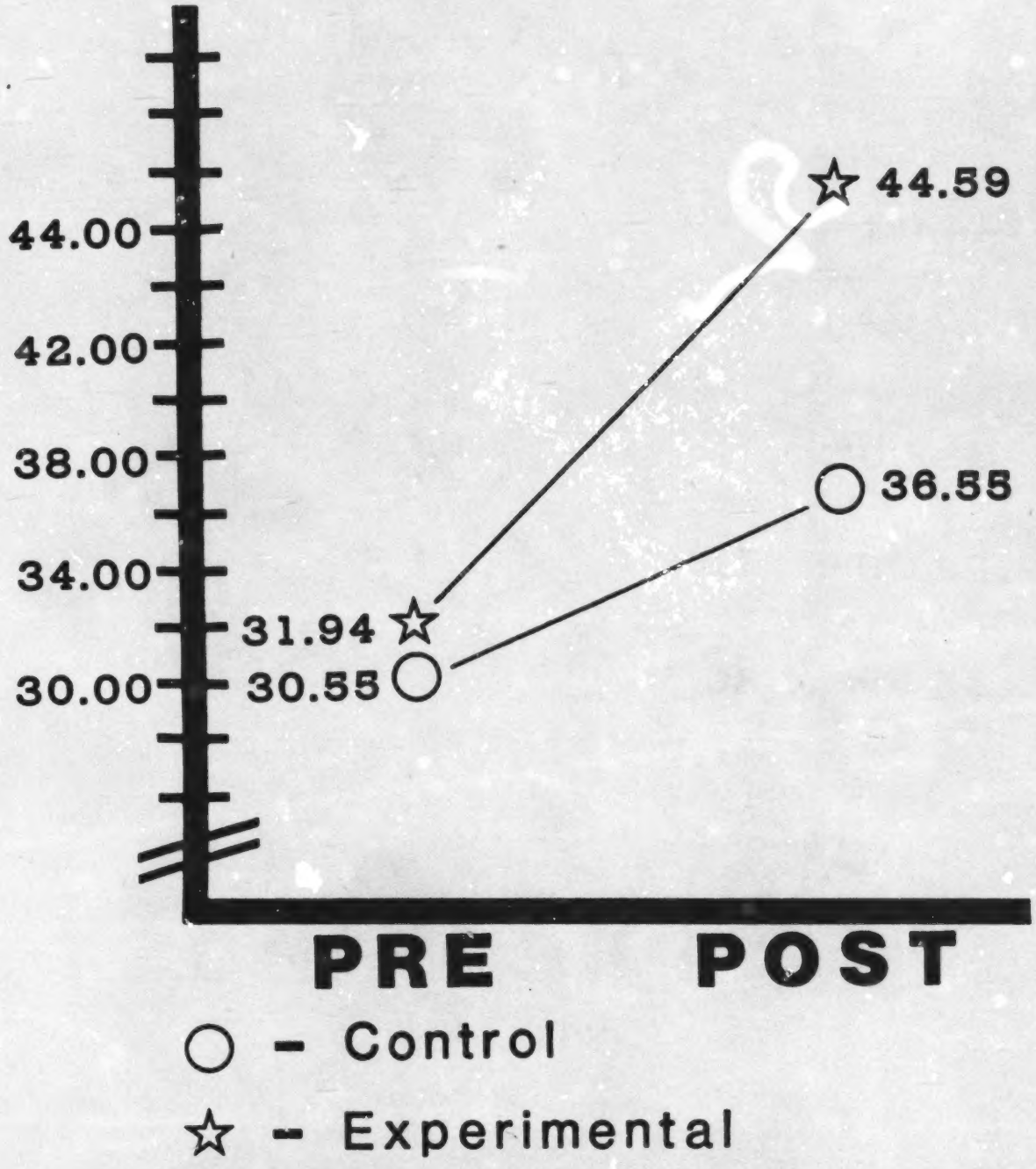


FIGURE 10

BSCS pretest and posttest scores at School 3.

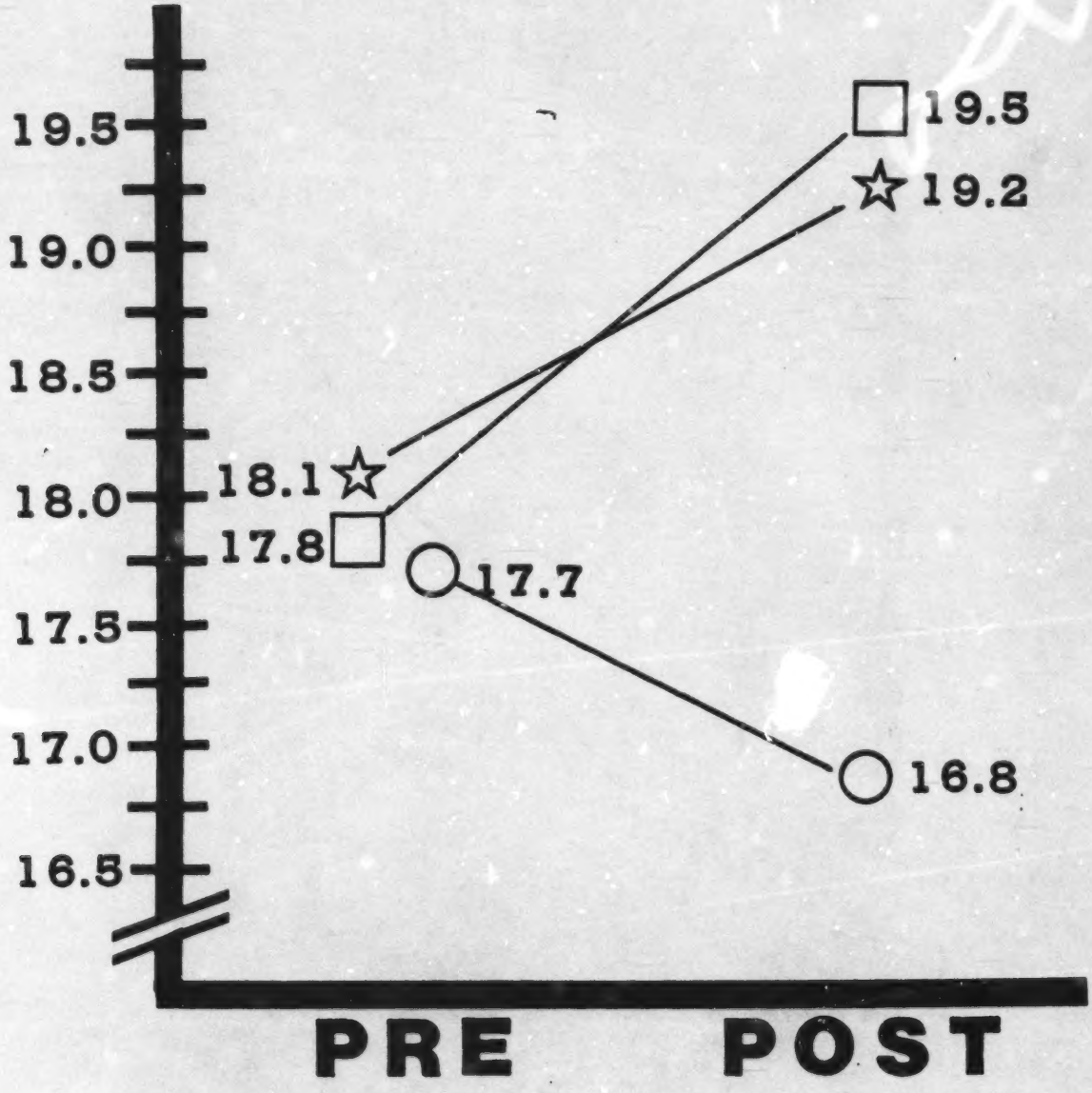


FIGURE 11

TIPS pretest and posttest scores at School 3.

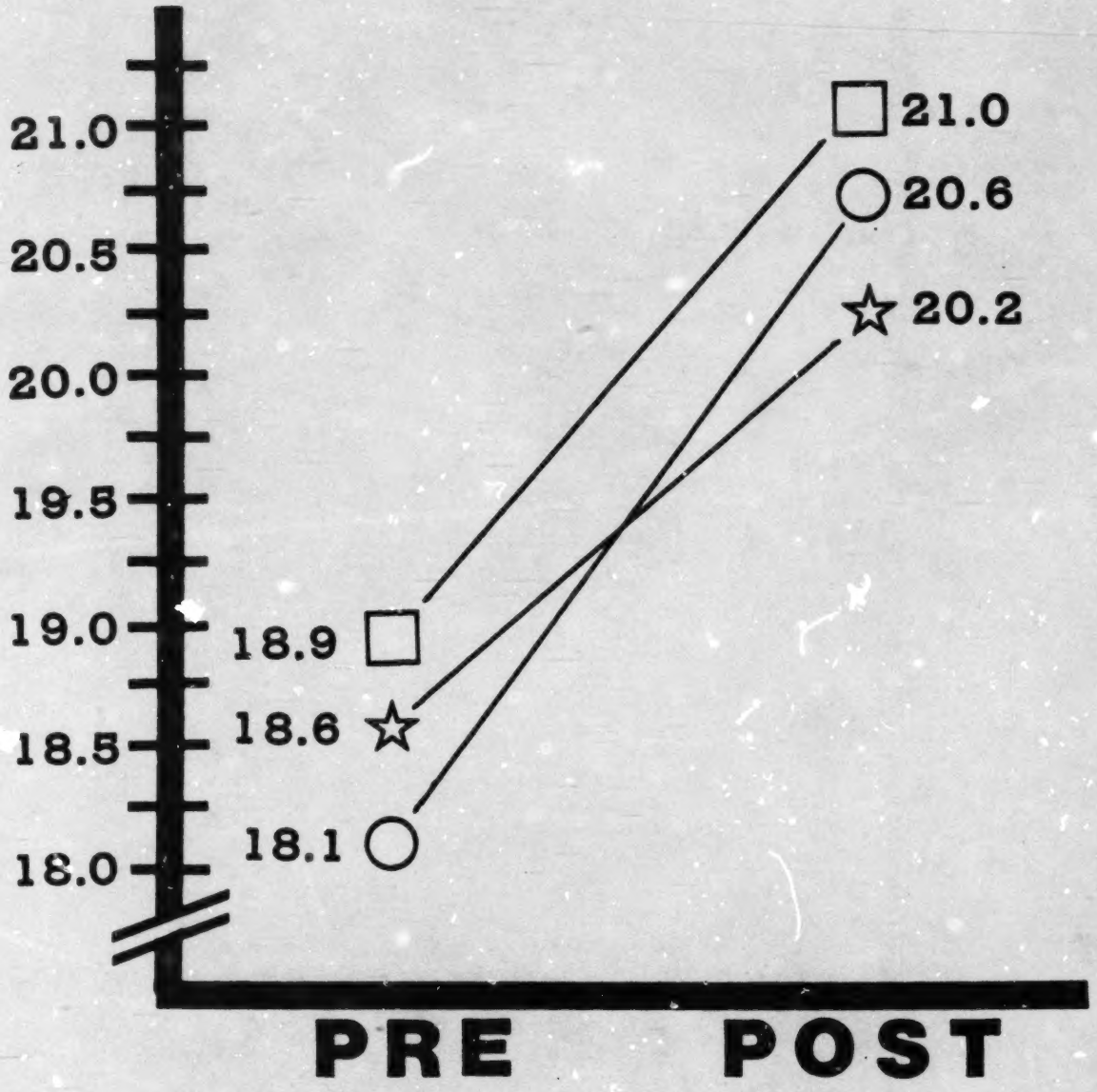
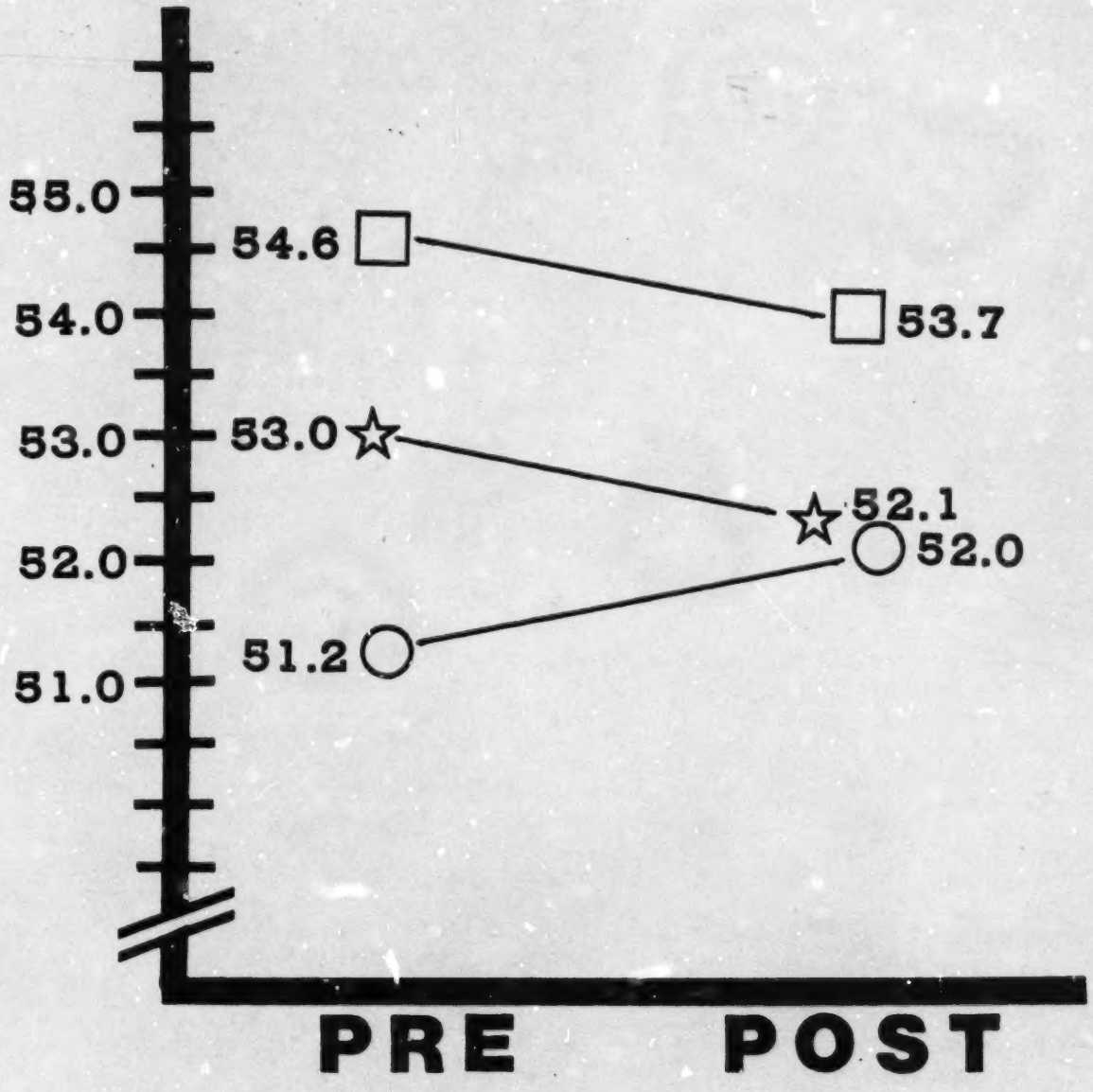


FIGURE 12

Watson-Glaser pretest and posttest scores at School 3.



○ - Control

□ - Guided ☆ - Unguided

Appendix A
Description of Programs

PLANT: A Plant Growth Simulation. PLANT is a student-interactive simulation which explores the relationship of light intensity and light duration to the growth and development of a green plant. Students may manipulate the light condition and observe the effects on plant growth. The computer generates a graphic (pictorial) representation of the growing plant. Students can measure plant height, leaf size, and leaf internode distance of the graphic image. Control of variables and the drawing of sensible cause-and-effect conclusions is stressed. The students develop problem solving skills and skills of measurement, tabulation, and graphing. The computer simulation is integrated with a teacher's guide and a student laboratory guide which provides additional real laboratory experiences.

BALANCE: A Predator-Prey Simulation. BALANCE is a student-interactive simulation which explores the interrelated variables affecting predator-prey relationships. Manipulation of variables of food supply, carrying capacity, environmental conditions, and external pressures is possible. Tabular and graphic output is provided to illustrate the effects of the variables on the related population. The student develops scientific problem solving skills as well as skills of tabulation, graphing and interpretation. The students record data in a student laboratory guide which provides realistic scenarios for exploration.

OSMO: Osmosis in Red Blood Cells. OSMO is a student-interactive simulation which explores various osmotic conditions in red blood cells. The student is able to study the effects of placing a red blood cell in hypertonic, hypotonic, or isotonic solutions. A computer generated graphic (pictorial) representation of the cross section of a red blood cell changes according to the osmotic conditions. Students develop an understanding of diffusion, osmosis, permeability, and equilibrium. Students learn controlled experimentation and develop scientific problem solving skills through interaction with a realistic simulated experiment. The computer simulation is integrated with a teacher's guide and student laboratory guide which provides additional real laboratory experiences.

MOTHS: Peppered Moth Evolution. MOTHS is a student-interactive simulation based upon the historical occurrence of peppered moth evolution in industrial England. The student may examine the effects of changes of the type of environment on the numbers of light-colored and dark-colored peppered moths in a population. The MOTHS model considers the initial numbers of light-and dark-colored moths, selection pressures, and the likelihood

of mutations. Students develop scientific problem solving skills in addition to learning the concepts of selection, mutation, gene pool, gene frequency, and the Hardy-Weinberg principle. The computer simulation is integrated with a teacher's guide and a student laboratory guide.

ENZYME: A Simulation of Enzyme Action. ENZYME is a student-interactive simulation which studies an application of the lock and key model of enzyme action. Using the enzyme acetylcholinesterase, students may explore enzyme action and the effects of inhibitors. Students may compare the structures of inhibitors to that of the substrate, and they may examine the impact of inhibitors on the rate of breakdown of the substrate. Tabular and graphic output is provided. The computer simulation is integrated with a teacher's guide and a student laboratory guide. The extensive accompanying written materials enable the learner to apply the lock and key model in order to develop scientific problem solving skills and to come to an understanding of enzyme regulation of the chemical activities of organisms.

MONOCROS: Monohybrid Crosses. MONOCROS is a student-interactive program which simulates various monohybrid genetic crosses. The student can experiment with crosses involving known genotypes as well as with unknown genotypes. In addition, the student can "teach" the computer a new trait and then make crosses involving that trait. By performing the experiments suggested in the accompanying student's laboratory guide, the student will develop scientific problem solving skills while learning the concepts of phenotype, genotype, dominance, and test cross. By providing concrete examples of abstract concepts, this program provides a good introduction to basic Mendelian laws.

DICROSS: Dihybrid Crosses. DICROSS is a student-interactive program which simulates various dihybrid genetic crosses. Using the program, the student can set up various types of dihybrid crosses and examine the offspring generated by the computer. By running experiments from the accompanying student's laboratory guide, the student will improve problem solving skills while developing the concepts of linkage, sex linkage, and probability. This unit reinforces the understanding of concepts presented in MONOCROS. By providing concrete interaction with abstract ideas, this program provides a good introduction to dihybrid Mendelian genetics.

POLLUTE: Impact of Water Pollutants. POLLUTE is a student-interactive simulation which examines the impact of various pollutants on typical bodies of water. The accompanying student's laboratory guide directs the student to study the impact of water temperature, waste type, waste treatment type, rate of waste dumping, and type of receiving

body of water on the oxygen content of the water and the survival of fish living in the water. The computer generates tabular and graphic data to enable the student to test various hypotheses. This is an appropriate unit for biology, ecology, or environmental studies classes.

DILUTE: Microbial Dilution Series. DILUTE is a student-interactive simulation which mimics a microbial dilution series. The student is able to design and test his/her own dilution series to determine the concentration of a known or unknown bacterial solution. The computer provides a graphic (pictorial) representation of a resulting culture plate of bacterial colonies. The student will master concepts related to concentration, sterile technique, titer, and pipetting. The program can be used as a "stand alone" demonstration of laboratory technique or as an introduction to or reinforcement for actual experiments in microbiology.

CLASSIFY: Classification Key Program. CLASSIFY is a student-interactive simulation which allows students to develop classification keys for living organisms. The computer presents an unclassified set of characteristics and labels for classification at various levels. By looking for patterns grouping characteristics appropriately, and assigning correct labels, the student comes to understand the underlying logic of classification keys. The accompanying student's laboratory guide enables the student to apply these classification strategies to actual living organisms.

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